A Logic-Based Approach to
Discourse Analysis

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Tomek Strzalkowski
Courant Institute of Mathematical Sciences
New York University
New York, NY 10012

Abstract

A first step toward automating the process of discourse understanding is to grasp the meaning contents of the discourse message, at least the literal meaning. Although every utterance may be assumed to contribute something to the discourse meaning as a whole, this latter can only rarely be regarded as a simple sum of meanings of component utterances. Utterances, or sentences, making up a discourse are usually involved in complicated mutual dependencies, that often go beyond the text itself. A careful study of these extra-sentential and inter-sentential dependencies in discourse is necessary before a more successful attempt to design an automated discourse understanding system can be undertaken. We outline a fragment of the system of semantic rules for computing coherent continuations at any point in discourse by uncovering various links existing between an utterance and its context. Next, we describe an extension of the method to handle changes in the level of reference in discourse. In order to accomplish this we develop a multi-level model for representing and manipulating various types of non-singular terms. We outline a possible application to processing expository texts found in college textbooks on science and engineering.

1. Computing extra-sentential dependencies in discourse

A first step toward automating the process of discourse understanding is to grasp the meaning contents of the discourse message, at least the literal meaning. A discourse normally consists of more than a single utterance, and although every utterance may be assumed to contribute something to the discourse meaning as a whole, this latter can only rarely be regarded as a simple sum of meanings of component utterances. Utterances, or sentences, making up a discourse are usually involved in complicated mutual dependencies, that often go beyond the text itself. A careful study of these extra-sentential and inter-sentential dependencies in discourse is necessary before a more successful attempt to design an automated discourse understanding system can be undertaken.

Suppose that in an automated processing of a natural language discourse we have reached the stage where sentences (or utterances) are represented with parse structures in some grammar. Let L be a fragment of a language of such parse structures that can represent sentences from a selected subset of English. L is identified here with the set of phrase-markers that can be generated from English sentences with a categorial grammar CAT (Montague 1974). It is not necessary that we take a categorial grammar to base the syntactic process on; perhaps some other syntactic system would be more suitable in practice. Nonetheless the simplicity and elegance of CAT make this grammar most suitable for this presentation. We concentrate on the translation of some example expressions, sentences and paragraphs of L into well-formed formulas of a λ-categorial language Λ that would give representation of both a sentence's logical form and its cohesive links to the surrounding discourse. In particular, we shall look closely at the cohesive links created by inter-sentential anaphoric references appearing in different contextual situations.

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A formal definition of language Λ is given elsewhere (Strzalkowski&Cercone 1986). Λ possesses adequate expressive power to represent the meaning of a considerable spectrum of linguistic constructs found in a natural language discourse. What is of a particular interest to us, Λ provides a natural and uniform means for computing and representing extra-sentential dependencies. As we shall see in the next section, a meaning representation language so-defined is still inadequate for capturing some more difficult cases which we call remote co-references.

Our present effort is to describe a transformation ISD such that ISD $\subseteq$ L $\times$ Λ, and whenever a source expression in L consists of more than one sentence, a class of intersentential dependencies within this fragment is identified and resolved, if possible. It must be noted here that ISD represents a semantic process which is entirely independent of any pragmatic or domain related factors. As a result a substantial amount of domain-oriented ambiguity may be left unresolved. In any practical application, this transformation must be accompanied by a pragmatic process, as described in (Strzalkowski 1986). ISD consists of a collection of translation rules $\{R_1, R_2, \cdots\}$, such that each rule is responsible for translating a specific type of dependency. Actually, only Rule 1 works directly on expressions of L, translating them into "literal" representations in Λ, independent of one another. Rules numbered 2 and up will take these "literal" translations and try to relate them pairwise looking, among other things, for unresolved anaphoric references. Most of these rules can be written in terms of two distinguished expressions of Λ, S_1 and S_2, which we call *the context-setting sentence* and *the current sentence*, respectively. Expression S_1 is a Λ-representation of the linguistic context in which the sentence with translation S_2 is to be evaluated. Neither S_1 nor S_2 must correspond to surface sentences, though. S_1 may represent a larger part of discourse, perhaps an entire paragraph; on the other hand, S_2 may constitute only a subclause of S_1 in which case we would talk of intra-sentential dependency. It should be noted here that the potentially explosive number of possibilities will be in fact limited by the actual structure of the discourse under consideration (see, among others, Grosz and Sidner 1985), as well as by the pragmatic and domain-related information, not discussed here.

Let us now consider a two sentence paragraph given below:

S_1: *John interviewed a candidate.*
S_2: *The guy had impressive references.*

In the most natural reading of this paragraph, the anaphor of *the guy* is resolved against *a candidate* in the first sentence, so that the second sentence actually means: *the guy whom John interviewed had impressive references.* This inter-sentential dependency is captured by the translation rule 2, which operates on the "literal" translations of both sentences as delivered by Rule 1 (Strzalkowski & Cercone 1986).

Rule 2 (Perfect-Context Translation Rule)
If the context-setting sentence S_1 has a referential interpretation in the form $\exists u\ [P(u)\ \&\ F(u)]$, and the current sentence S_2 contains an unresolved definite anaphor, that is,

$$S_2 = \exists u\ [C(u)\ \&\ P_1(u)\ \&\ F_1(u)\ \&\ \forall x\ [\{P_1(x)\ \&\ C(x)\} \supset (x=u)]],^2$$

then this anaphor can be resolved against S_1, and the resulting translation of S_2 is obtained as

$$\lambda C\,[S_2](\lambda u\,[P(u)\ \&\ F(u)]).$$

[2] C is a free predicate variable that can be bound by the sentence's context. It has been introduced by Rule 1 with the translation of the definite article.

In the example above, the second sentence obtains the desired translation as shown below

$$\exists x\ [guy(x)\ \&\ cand(x)\ \&\ int(J,x)\ \&\ had\text{-}imp\text{-}ref(x)\ \&$$
$$\forall y\ [\{guy(y)\ \&\ cand(y)\ \&\ int(J,y)\} \supset (x=y)]]$$

A somewhat different problem arises when we consider a fragment with a possible non-referential interpretation, as in

John wants to marry a queen. The girl must be rich and pretty.

Now, Rule 2 can compute the anaphoric link between *the girl* and *a queen* only if *both* sentences receive their referential interpretations. In case where *both* sentences are understood non-referentially, we have to use Rule 3, given below. No other combinations are possible.

Rule 3 (Imperfect-Context Translation Rule)

If the context-setting sentence S_1 has a non-referential interpretation in the form **imp** $(\exists u\ [P(u)\ \&\ F(u)])$, [3] *where* **imp** *is an imperfect operator, and the current sentence S_2, also in a non-referential interpretation, contains a definite anaphor which occurs in scope of an imperfect operator* **imp**$_1$, *i.e.,*

$$S_2 = \mathbf{imp}_1(\exists u\ [C(u)\ \&\ P_1(u)\ \&\ F_1(u)\ \&\ \forall x\ [\{P_1(x)\ \&\ C(x)\} \supset (x=u)]],$$

then this anaphor can be resolved against S_1, with the resulting translation of S_2 derived as

$$\lambda C\,[S_2](\lambda u\,[P(u)\ \&\ F(u)]).$$

Rule 3 encompasses a large class of non-referential contexts, which we call imperfect contexts, and which involve constructs including propositional attitudes (*want, try, wish*), intensional verbs (*seek, conceive, think about*), other complement-taking verbs (*go, come*), modal verbs (*must, can, will*), as well as progressive tense forms. In the non-referential interpretation, the second sentence of the fragment given above will be translated with Rule 3, resulting in the following formula

$$must(\exists x\ [girl(x)\ \&\ queen(x)\ \&\ marries(J,x)\ \&\ rich(x)\ \&\ pretty(x)\ \&$$
$$\forall y\ [\{girl(y)\ \&\ queen(y)\ \&\ marries(J,y)\} \supset (x=y)]])$$

Other studied cases of inter-sentential anaphora (see Strzalkowski 1986a-c, Strzalkowski & Cercone 1986) include non-referential interpretation of discourse fragments involving attitude report verbs (*believe, know, disagree*). These cannot be translated with Rule 3, and a new rule, Rule 4, is developed to compute anaphoric links in texts similar to the one given below.

John believes that a unicorn lives in the park.
He thinks the creature has a long horn.

Rules 5,6 and 7 account for the pronominal anaphora, Rule 10 deals with certain instances of attributive use of definite noun phrases. Rules 8 and 9 are used when the antecedent of an anaphor is a proper name rather than a description. This is the situation where an interesting type of referential ambiguity occurs whose resolution may have far reaching consequences on the process of discourse understanding. In the following fragment

Sylvester tries to catch a bird. The cat is clumsy.

there are two possible ways of linking *the cat* with *Sylvester*. In one reading, not very different from those processed with Rule 2, the definite anaphor refers primarily to the entity which can be described as *the one who tries to catch a bird*, and only contingently to its name. In this case we acquire some new information about Sylvester, namely that it is a cat. In the other possible

[3] Here **imp** stands for a compound operator, classified into category (t/e)/t, such as *John wants*.

reading, the anaphor refers to the name only, and thus may draw on some context which is different from the first sentence in the fragment. This latter situation is handled by Rule 9.

Rule 9 (Names as Ultimate Referents)
If the context-setting sentence S_1 has the form of $F_1(N)$ where N is an individual constant denoting a name, and the current sentence S_2 contains a definite anaphor, so that its literal translation has the form

$$S_2 = \exists x\ [P(x)\ \&\ C(x)\ \&\ F_2(x)\ \&\ \forall y\ [\{P(y)\ \&\ C(y)\} \supset (x=y)]],$$

then the anaphor can be resolved against N as its ultimate referent with the following derivation:

$$\lambda p\,[p(N)](\lambda x\,[\lambda C\,[S_2](\lambda s\,[\tilde{N}(s)])])$$

where $\bar{N}$ is the predicative use of name N.

In the above fragment, Rule 9 would produce the following translation for *the cat is clumsy* (S is an individual constant denoting the individual named Sylvester):

$$cat(S)\ \&\ Syl(S)\ \&\ clumsy(S)\ \&\ \forall x\ [\{cat(x)\ \&\ Syl(x)\} \supset (x=S)]$$

There are more aspects of this transformation that merit attention. These include rules for dealing with other kinds of anaphora not discussed here, elliptical constructions, enumerably singular (plural) terms, intra-sentential anaphora and non-anaphoric dependencies, as well as indirect and forward reference cases where access to the speaker/hearer knowledge base may be required. We also have to deal with the changing reference level.

2. Non-singular terms in discourse

The rules discussed in section 1 cover selected cases of inter-sentential anaphora where the reference level in discourse does not change from one sentence to another. There exists, however, a class of inter-sentential dependencies whereby a reference is made across boundaries of different reference levels in discourse. For example, in

My new pet is an alligator. But the alligator cannot live in our climate.

the alligator in the second sentence most likely refers to a generic object of which the alligator in the first sentence is an instance or extension. Thus we can say that the second alligator is a non-singular *superobject* in which the first alligator somehow participates. The extent of such participation is not clear, but in general it can be observed that certain predications true of complexes of different kind are not preserved for their parts or elements, and vice-versa. To represent this new kind of inter-sentential dependency we introduce a multi-level model for interpreting natural language expressions, such that the levels in the model would correspond (roughly) to the levels of reference in discourse. For instance, in the example above, the resulting representation would have both alligators placed at different, though related, "object levels". Because of an inherent subjectivity of such classifications, the levels in the model may have fuzzy boundaries and are only partially ordered with the *lower than* (i.e., *more detailed than*) relation with respect to some current level (corresponding to the level of reference at a present point in discourse).

The basic concepts of the theory are the notions of a singular object and a coordinate, a usually ordered set specifying a type of "dimension" that the object in question spans. The most common of these coordinates are time and space but other more abstract ones are also possible. These two basic concepts are then used to define the notion of the object's *instance* with respect to some coordinate. Thus, the pet alligator in the example above is related to the generic concept of alligator by some "species" coordinate that somehow ties (or enumerates?) all alligators around the world. If we reverse this process we can combine objects into complexes to which we can subsequently refer using *collective* terms, singular or plural, such as, for example, *people*

or *the man* (generic). The *lower than* relation between levels in the universe model derives from expanding the notion of instance over collections of objects. The relation introduces a partial ordering within the universe model and thus helps to trace changes in the reference level of discourse. The highly discrete approach taken here is favorably contrasted with other existing approaches to non-singular terms, including (Quine 1960), (Kripke 1972), (Montague 1974), (Carlson 1982) and others. While insights of Quine, Kripke and, perhaps even more so, Carlson are undoubtly of great influence, they require reworking in more discrete terms. Finally, we may note that the research in Artificial Intelligence and Computational Linguistics has devoted relatively little attention to treatment of non-singular terms in natural language in general and in natural language discourse in particular; see, however, (Sidner 1979) for some early attempts to recognize generics in discourse. One of the goals of the present research is to fill this gap.

3. A multi-level model for interpreting natural language terms

Initially, we note that our language tends to deal with singular objects only, no matter how complex their structure happens to be. A singular object is therefore any entity that can be taken as a coherent whole, in other words, it can be referred to directly using a referring expression of language: a name, a definite description, a pronoun. Thus, at least as far as our ability to refer is concerned, all objects appear singular. Still, it is not the case that all objects are singular in the same way. Take, for example, two persons John and Mary. They are singular objects and they seem singular in the same way, in other words, singular relative to one another. Next take alligator, the species, and the alligator John owns. Although both are singular in their own right, they are not compatible when related to one another: the alligator John owns appears only a manifestation, or extension, of alligator the species at a certain space-time location.

Let us introduce, only intuitively at first, the relation of *relative singularity* among objects, as suggested above. This relation will help us to break down the universe of objects into classes of relatively singular objects, which we call *levels*. The levels can be subsequently partially ordered with *lower than* relation, i.e., $L_1 < L_2$, indicating that level L_1 consists of manifestations (extensions, instances) of objects at level L_2. Let L_0 be an arbitrary level we select as our reference point; if our discourse operates at this level then L_0 defines the current *level of reference* of the discourse. Let L_{+1} and L_{-1} be two other levels different than L_0 and such that $L_{-1} < L_0 < L_{+1}$. At level L_{+1} we place the objects we consider to be generalizations (or abstractions) of some measurable amount of objects from L_0. It is only from the perspective of L_{+1} that we are able interpret *The tiger lives in the jungle,* or *The president is elected every four years,* or *Birds can fly*, or *Tourists start forest fires.* The objects at L_{+1} are singular but only when related to one another within the same level; when viewed from L_0 they appear "generic" or "functional" or the like, in other words, non-singular. Non-singular objects may not have corresponding measurably singular descriptions at L_0 (like *every tiger, some president*, etc.), and often it will not be possible to refer to them in the terms of the language available at L_0. Thus, while the statement of *The President lives in the White House* interpreted at level L_{+1} can be argued to be equivalent to the statement *Every president lives in the White House* interpreted at L_0, the same cannot be said of *The tiger lives in the jungle* and *Every tiger lives in the jungle.* We must note that some objects found at L_{+1} could have been placed there by design rather than as a result of generalizing from L_0; an example of such higher-level object may be **The President**.

If level L_{+1} contains generalizations of objects from L_0, then level L_{-1} will contain their specializations or extensions. Descending upon L_{-1} we can see that what we previously

considered to be *the atom* actually denotes many different kinds of atoms (H, O, Ca, Fe, etc.), or that *the mail* is not the same every morning.

A few definitions will help to put the above intuitions into a more formal setting.

Def. 1. *A use of a description is called singular if it refers to a singular object. A use of a description will be called measurably singular if it refers to some measurable quantity of a singular object; otherwise we shall talk of non-singular use.*

Def. 2. *An object level, or simply a level, is an arbitrary collection of relatively singular objects. On the language side, the corresponding reference level encompasses those singular and measurably singular uses of descriptions that refer to the level's objects.*

Def. 3. *For any level L_n, there are at least two distinct levels L_{n-1} and L_{n+1} such that L_{n+1} contains the non-singular objects as seen from L_n, and L_{n-1} contains the objects for which the objects at L_n are non-singular.*

Def. 4. *The level L_0 is an arbitrarily chosen level serving as a reference point.*

As described, the structure of levels is not yet adequate to capture the full complexity of the reference structure of discourse. A notion of coordinate has to be introduced along the following lines. We shall call T a *coordinate*, if T is a set of "points" or "locations" at which certain general (or abstract) objects, for example *the president* or *the atom*, are assigned more specific extensions or instances, such as *President Reagan* or *H, Fe, Ca, ...* A coordinate is usually an ordered set though the ordering may be partial only. Almost any object we can think of appears an instance of a more general concept, and often there will be more such concepts available, if we consider different coordinates. Water in a glass is an instance of some totality of water in the universe (space coordinate), and also an instance of a concept of water as in *water boils at 100 degrees Celsius.* These examples suggest that a coordinate is usually a large set, often an infinite set, though perhaps no more than recursively enumerable. A non-singular object can be decomposed into instances in more than one way, depending which coordinate is used. Let $L_{-1}^{\mathbf{N},T}$ be the level where we place the instances of object **N** decomposed with coordinate T. By analogy, we define $L_{+1}^{\mathbf{N},T}$ to be the level such that for any object **M**, $\mathbf{M} \in L_{+1}^{\mathbf{N},T}$ if $\mathbf{N} \in L_{-1}^{\mathbf{M},T}$. In other words, $L_{+1}^{\mathbf{N},T}$ contains the superobject **M** generalizing over object **N** with the use of coordinate T.

Suppose that we have an object **N** called N at level L_0. Suppose further that coordinate T is selected so that for any $x,\ y \in T$ we have that $\mathbf{N}$-at-$x \neq \mathbf{N}$-at-y. Let us use $\mathbf{N}_x$ to stand for **N**-at-x, where x is an element of T, and let (N x) be an expression in our meaning representation language that refers to (or denotes) object $\mathbf{N}_x$, whenever an expression N refers to **N**. We obtain therefore that

$$\forall\ x,y \in T\ [x \neq y \supset (\mathrm{N}\ x) \neq (\mathrm{N}\ y)]$$

The new objects $\mathbf{N}_x$'s cannot be placed at L_0 because, being instances of **N**, they are not singular relative to **N** (see Def. 2). Instead, we move them onto a new level $L_{-1}^{\mathbf{N},T}$ leaving the original object **N** at L_0. We say that the level $L_{-1}^{\mathbf{N},T}$ is lower than the level L_0, and write $L_{-1}^{\mathbf{N},T} < L_0$. Often we drop the superscripts N and T over the level symbol, assuming some lower level L_{-1}, whenever it does not lead to ambiguity.

As an example, let us consider a rather naive concept of bird, **B**, as that of a winged creature that lay eggs, and place it at L_0. Using a genus coordinate, G, we can construct a level $L_{-1}^{\mathbf{B},G}$ containing such objects as **eagle, hawk, goose**, and **penguin**. There is another way of interpreting concept **B** as well: we introduce a *specimen* coordinate S that allows us to pick up specific birds, such as Opus, the penguin, at level $L_{-1}^{\mathbf{B},S}$. Note that this level is lower than $L_{-1}^{\mathbf{B},G}$

because it contains all levels $L^{X,S'}_{-1}$, where X ranges over objects at $L^{B,G}_{-1}$, and $S' \subseteq S$. Now we can attempt to represent meanings of some simple statements about birds. For example, *Birds can fly* is represented at L_0 as can-fly(B), while *Opus is a bird* would translate as $\exists s \in S$ [(B s) = Opus]. We cannot infer from these statements that *Opus can fly*; indeed, *Opus cannot fly*, which translates to ¬can-fly(Opus), is not necessarily inconsistent with the above two.

A process reverse to decomposition is that of ascending to a higher level within the level hierarchy. Suppose that for some objects N_1, N_2, $\cdots$, considered distinct at L_0, we discover they share a certain property, such as being an N, so that we need a generalizing concept to talk about them. We pick up a coordinate T, and climb onto some *higher* level L_1, that is, $L_0 = L^{N,T}_{-1} < L^{N_i,T}_{+1} = L_1$, and establish a new object **N** there, a *superobject*. Now, as viewed from L_1, all N_i's are just the occurrences of **N** at different values of coordinate T. It is important not to confuse a superobject with a set **S** of its instances at L_0 that gave birth to this superobject. A superobject **N** can be identified with a family of functions $\{N_T \mid T \text{ is a coordinate}\}$ such that each N_T is a function from coordinate T into an appropriate lower level, $L^{N,T}_{-1}$. In particular, a superobject **N** at L_1 can be viewed from L_0 as a function N_T from T into L_0 such that, whenever $s \in \mathbf{S} \subseteq L_0$, then there is $t \in T$ such that $N_T(t) = \mathbf{N}_t = s$. The function N_T is then arbitrarily extended beyond the set **S**. The following definition may be suggested.

Def. 5. *Let L and M be any two distinct levels of relatively singular objects. We say that level L is lower than level M, L < M, iff there exists an object* **P** *at level M and a coordinate T such that* $L \supseteq M^{P,T}_{-1}$.

4. Remote co-references in discourse

We now examine how the foregoing theory of non-singular terms could be utilized to account for some more advanced cases of inter-sentential dependencies in discourse. Let us start with an example and consider the following discourse fragment.

The president$_1$ is elected every four years. The president$_2$ is Reagan.

Suppose that the president$_1$ and the president$_2$ are interpreted at levels L_1 and L_2, respectively, so that one of the following takes place. Either $L_1 = L_2$, or $L_1 < L_2$, or $L_2 < L_1$, or simply $L_1 \neq L_2$, where < stands for the *lower-level* relation introduced in Def. 5. The latter case does not interest us, since, in such an interpretation, both sentences were uttered at different occasions with no connection between them. Consider first that $L_1 = L_2 = L_0$. If the two definite descriptions were to co-refer then we would be talking of the same object (individual) in both sentences. That interpretation, although possible, does not agree with our intuition. In this case the conclusion of *Reagan is elected every four years* follows immediately. Assume then that $L_2 = L^{TP,T}_{-1} < L_1 = L_0$ where **TP** is the object at L_1 referred to by the president$_1$, and T is a coordinate. If the president$_1$ is used as a name, we can expect the following translations, respectively:

$elected\text{-}every\text{-}4years\,(TP)$

$\exists t$ [SL(t) & ((TP t)=R)]

where $t \in T$ and SL is a selector over T provided by the discourse situation (for example *now, here,* etc.). [4] We summarize the above as follows. In some part of a discourse, a certain

[4] In a more general case, we would take the phrase *the president$_1$* as an ordinary definite description, assuming some external context C which allows for the use of the definite article (Strzalkowski & Cercone 1988).

(general) object **X** is addressed; that is, there is some part, S_1, of the discourse (presented as a single sentence in our examples, for simplicity), such that S_1 predicates something of **X** - that is, $S_1(X)$, where X is a description that refers to **X**. In a subsequent part of the discourse, however, the discourse changes the level of reference and only some instance(s) of **X** with respect to some coordinate T is addressed; that is, there is some $t \in T$ such that $S_2((X\ t))$, where S_2 is this new part of the discourse. Apparently, the discourse internal cohesion would be compromised if we did not allow the higher level object **X** be a target of a remote reference by a description (X t) denoting one of its instances. In such a case we say that $S_1(X)$ creates a supercontext for (X t). We can further say that X and (X t) are *remotely co-referential.* This type of inter-sentential dependency is captured by the translation rule below.

Rule 11 (Supercontext Translation Rule)

If the context-setting sentence S_1 *with the translation* $\exists x\ [P_1(x)\ \&\ F_1(x)]$ *is interpreted at level* $L^{\xi;T}_{\ddagger 1}$, *where* ξ *is an object satisfying sentence* S_2 *when interpreted at level* L_0, *and* S_2 *contains an unresolved remote reference* P_2, *that is,*

$$S_2 = \exists y\ [P_2(y)\ \&\ F_2(y)],$$

then the full translation of S_2 *is obtained by*

$$\lambda Q[\lambda C[M_{Q,C}](C_1)](\lambda u[\exists t[\lambda y[P_2(y)\ \&\ F_2(y)]((u\ t))]]),$$

where the supercontext C_1 *is* $\lambda x[P_1(x)\ \&\ F_1(x)]$, *and* $M_{Q,C}$ *abbreviates the following expression*

$$M_{Q,C} = \exists x[C(x)\ \&\ \forall y\ [C(y) \supset (x=y)]\ \&\ Q(x)].$$

A similar situation (though not quite just a mirror-image situation) occurs when an expression addressing a higher level object is used to provide an inter-sentential link to a discourse entity that refers to an instance of this object. For example, *Look, a tiger! Careful, tigers are dangerous animals.* This is, however, just the tip of an iceberg. One of the important issues which remain to be worked out is how to automatically determine when a change of reference level in discourse takes place. Surely, a bare plural, such as *tigers* indicates a higher level reference, especially when co-related with a singular indefinite description, such as *a tiger.* Also, a singular definite description when followed by a co-related indefinite description or a definite plural, would normally indicate transition to a lower reference level (*The tiger has stripes. I saw one in the zoo.*). Another problem is to determine exactly what kind of inferences can be made along a remote co-reference link. At this time we disallow any such inferences whatsoever, to avoid certain unreasonable conclusions. Nonetheless, in many situations inter-level inferences can and should be made, or we risk to forsake our understanding of the discourse. The most obvious cases are those of generic-to-specific inferences, whereby a property attributed to a non-singular generic object (such as in *tigers are dangerous*) is reduced to a form of quantification over instances of this object at a lower level. This latter issue is addressed elsewhere (Strzalkowski 1988).

5. Processing expository texts

An application area we have been considering is the processing of expository texts, similar in character to those found in college textbooks on science and engineering. The language of science textbooks is rich in the variety of inter-sentential dependencies, including anaphoric references and remote references. The idea is to do an automated analysis of the logical structure of such texts by translating them into an adequately rich and faithful meaning representation which could be subsequently used in a deductive/retrieval process. This representation is

expected to capture the multiple ways in which the elements of the text are interconnected, indicating a number of plausible interpretations. Pragmatic information will be added gradually, but even then the domain-related information will be kept at the most general level possible so that the results could retain a maximum universality. As an example, consider the following short paragraph excerpted from a college textbook of physics: [5]

> In electricity the isolated charge q is the simplest structure that can exist. If two such charges of opposite sign are placed near each other, they form an electric dipole, characterized by an electric dipole moment d. In magnetism isolated magnetic poles, which would correspond to isolated electric charges, apparently do not exist. The simplest magnetic structure is the magnetic dipole, characterized by a magnetic dipole moment μ. (pp. 823-824)

Looking at the first two sentences of this paragraph, there is a clear remote co-reference link between them involving the phrases *the isolated charge q* and *two such charges of opposite sign*. The first of these sentences introduces a concept of the isolated charge, at some initial reference level L_0. In the second sentence, however, we change the reference level to some lower, or more detailed, level L_{-1} where we address a pair of instances of this concept. Note that the second sentence is still a general one: it does not refer to any specific situation, rather it describes a type of event that may or may not have any specific extensions. If we were to talk about such an extension, we would have to descend to a yet lower reference level, L_{-2}, with a pair of charges located with respect to time and space, and perhaps some other factors. These "other factors" are quite essential here, and we shall refer to them as *normality conditions*. Normality conditions actually determine which of the spatio-temporally located pairs of charges can be counted as creating instances of the generic event described on the upper reference level. Although some constraints are explicitly set in the generic event description (*placed near each other, of opposite sign*), some other are implicitly "understood" (no insulator between charges, etc.). Further analysis of the rest of the sample text could be continued along similar lines.

6. Conclusion

The area of inter-sentential dependencies in discourse has been given varying degrees of attention in linguistics, philosophy of language and in artificial intelligence research, see, for example, (Cohen 1978), (Partee 1978), (Sidner 1979), (Webber 1979), (Grosz 1981), (Hirst 1981), (Brown and Yule 1984) and (Hinrichs 1986). Formal linguistic and philosophical approaches to discourse analysis, while usually aiming at broader description of linguistic phenomena, normally are not directly suitable as a basis for a computational theory of natural language processing. Computational linguistic research, on the other hand, remained mostly application oriented and thus offered a limited range of solutions. In general, we observe that the research in the field of inter-sentential dependencies in discourse has not gone far beyond a limited domain of anaphoric in-text references. Even in this limited domain, however, there is a tendency to disregard cases where utterances have other than singular and extensional readings. Thus it comes as no surprise that various proposed representations are not as adequate and accurate as they should be. The present research seeks to avoid some of the above problems by a more careful selection of the meaning representation language, as well as by taking a broader, more comprehensive approach to the problem of inter-sentential dependencies.

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